EASTERN REGION TECHNICAL ATTACHMENT
NO. 92-9A
SEPTEMBER, 1992

IN SEARCH OF THE PERFECT WAVE - A NEW METHOD TO FORECAST WAVES ON THE GREAT LAKES

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1. INTRODUCTION

An AFOS graphical Great Lakes wave forecast has been developed for marine forecasters. The AFOS product is stored under NMCGPHGLW (Figure 1), and is generated on WSFO Cleveland's Great Lakes Marine Enhancement Unit's VAX computer system by using the Great Lakes Environmental Research Laboratory's GLERL/Donelan Two-Dimensional Wave Prediction model. Not only do NWS Great Lakes forecasters have a new guidance product, but they now have the opportunity to control the wind and temperature data, which the model uses as input.

2. BACKGROUND

Wave forecast guidance on the Great Lakes has been automated and produced by the National Weather Service since 1974 based on Model Output Statistics (MOS) wind and temperature forecasts (Schwab et al. 1984). The Great Lakes Environmental Research Laboratory (GLERL) has been running the GLERL/Donelan wave prediction model on an experimental basis since 1984 (Schwab 1987). The Marine Enhancement Unit at WSFO Cleveland, Ohio has used a slightly modified version of the GLERL/Donelan wave model since 1987 on a non-routine basis.

During the Fall of 1991, the Marine Enhancement Unit designed a method to run GLERL's wave model routinely on the unit's Digital VAX computer system. The results were quite impressive, especially when forecasters were allowed to modify the guidance before the model run.

3. WSFO CLEVELAND'S MODIFIED WAVE MODEL METHODOLOGY

3.1 Input Observed Data

First, the modified model spins the lake waves up or down based on observed data. Water temperatures are averaged for each lake and 48 hours of upwind observations are checked for encoding errors before utilization.

3.2 Create Guidance Message

Next, the wind and temperature guidance is formatted into a AFOS message called CLEGWNxxx, where xxx is either MIC, SUP, HUR, ERI, or ONT. The guidance sources for this message, are the LFM MOS temperatures (FPC) and LFM lake winds from the NMCMRPGLW product. This message (Figure 2), divides each lake into three parts: North, Central, South (Lakes Michigan and Huron), and West, Central, East (Lakes Superior, Erie, and Ontario). The message format allows for easy AFOS editing by the marine forecaster. Note in Figure 2, the wind speed is an average speed in knots. If gusts are expected, the wind must be adjusted up. TA is the ambient air temperature in °F.

To inspect the guidance, one must use the display feature in AFOS, D:CLEGWNxxx. If the values are acceptable, no action will be needed; however, if the forecaster wants to make changes, the message will need to be edited by using AFOS's preformat feature, E:CLEGWNxxx, and stored under cccGWNxxx where ccc is the WSFO node identifier of the office making the change. The message is transmitted with CLE as the addressee.

3.3 Start Model and Create Guidance Status Message

A forecaster will have approximately 1 hour from receipt of the message to make changes in the guidance. An AFOS message will then be created by Cleveland's VAX once the wave model is running. This message, Figure 3, will let the marine forecaster know if modified or unmodified guidance is being used for the model run.

3.4 Create Wave Graphic

The wave forecasts will be returned as an AFOS graphic, NMCGPHGLW (see Figure 1). The graphic is divided into three sections on each lake. Wave forecast heights are displayed for every 6 hours with a * beside each synoptic hour. If there is an error in the guidance (Lake Ontario, Figure 1), a set of 5 stars (*****) will be printed in place of the wave heights.

4. CASE STUDY

The following case study illustrates how well the model handles a relatively strong storm that passed just west of the Great Lakes. Observed winds and temperatures from meteorological buoys on each lake (Figure 4) were used as input data for this period.

This was a relatively simple case where the wind direction was easy to forecast as a large surface high was expected to move east across southern Canada while a low moved north through Minnesota (Figure 5). Figures 6 and 7 show the surface pressure pattern at 10 a.m. EST on 28 October 1991 and at 7 a.m. EST on 29 October 1991, respectively. The pressure gradient implied that the northeast winds over the eastern lakes would shift to southeast during the forecast period, and the east winds over the western lakes would become mainly southeast as the low tracked northward.

A uniform wind field was assumed over each lake and approximately 12 hours of data was used to spin the wave model up. Wave heights were interpolated from the model's gridded output. The model was run on data from each buoy with no interaction from other wind reports.

Figures 8 and 10 indicate that the average wind speeds were near gale force across Lake Superior, and approached gale force over northern Lake Michigan. Although the low weakened slightly as it tracked north, the pressure gradient became considerably stronger in 21 hours over the western lakes (Figures 6 and 7).

At buoy 45136 on Lake Superior (Figure 12), the waves built rapidly from 6 to 15 feet, between 0600 and 1000 UTC, due to a strong southeast fetch - the area in which waves were generated was greater than 100 statute miles. Winds peaked during this period, from the southeast at 30 knots, with gusts close to 40 knots.

Waves over northern Lakes Michigan and Huron (Table 1 and Figure 11) also ran high, in the 7 to 8 feet range. At buoys 45002 and 45003 the waves peaked at around the same time as on eastern Lake Superior. The winds at both buoys were mainly from the southeast during this period (Figures 9 and 11). Although buoy 45002 was closer to the low pressure center, the southeast direction provided a longer fetch causing the speeds to be slightly higher at buoy 45003, which resulted in waves running around a foot higher.

The waves on Lakes Erie and Ontario peaked at 1800 UTC, much earlier than on the other lakes. This was due again to a favorable northeast fetch of 20 to 30 knots. Because the winds gradually shifted from northeast to east through the forecast period, waves height on both lakes only dropped off slightly, with buoy 45139 on Lake Ontario remaining nearly steady at around 4 feet.

The forecasts in this case were quite accurate. The maximum error in wave heights (Table 1; Figures 10 and 11) was 2 feet, with an error of 1 foot, or less, more than 50 percent of the time. It is hard to comprehend that type of accuracy in a wave forecast, but in this case, one must remember that we used observed wind data as input.

At Cleveland, research findings during the last several months of testing are similar to GLERL's own in-house results. In general, when a correct wind/temperature profile is supplied to the wave model, the resultant wave forecast will be extremely accurate.

6. CONCLUSIONS

Remember, the GLW is not just another model product, but a wave forecast tool that allows the forecaster to make a judgement on the input winds and temperatures. We urge all NWS Great Lakes marine forecasters to experiment and modify their respective cccGWNxxx products.

The NMCMRPGLW winds will generally be a good starting point, but it has been our experience at Cleveland WSFO, that even a novice marine forecaster can improve on the MRP winds. For example, if one is expecting a great deal of gustiness; the wind speeds should be averaged up.

The Marine Enhancement Unit's goal is to improve and enhance the quality of marine forecasts and weather services on the Great Lakes. Use of the output from GLERL's modified model will be an important step toward accomplishing that goal.

7. REFERENCES

Schwab, D. J., J. R. Bennett, and E. W. Lynn, 1984: A Two-Dimensional Wave Prediction System, *NOAA Technical Memorandum ERL GLERL-51*, NOAA/Great Lakes Environmental Research Laboratory, Ann Arbor, 18 pp.

Schwab, D.J., 1987: Great Lakes Wave Prediction Model. *Great Lakes Forecaster Handbook.* National Weather Service Training Seminar for Great Lakes Operational Marine Forecasting, Ann Arbor, 11 pp.

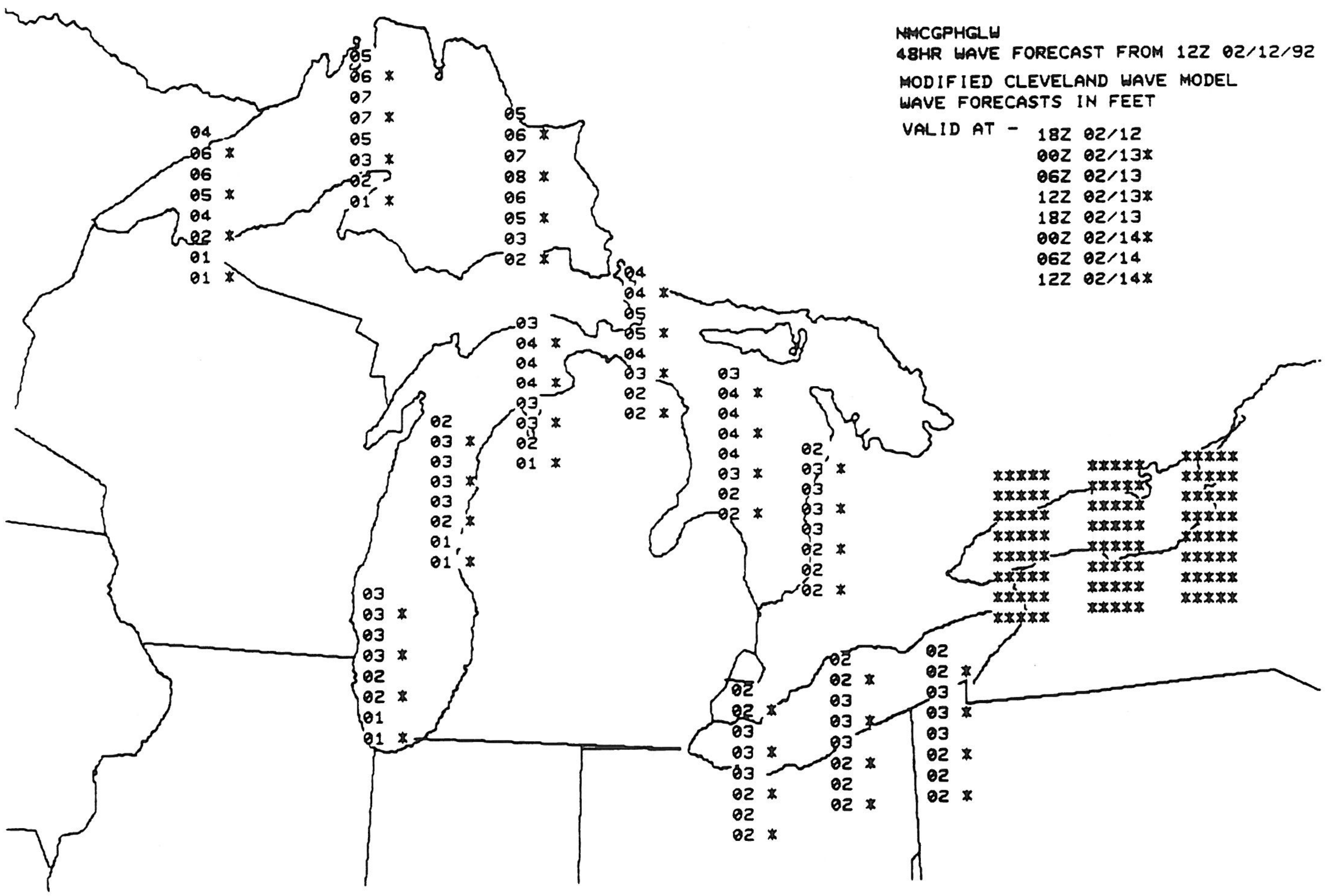

Figure 1. Cleveland Modified Wave Model AFOS Graphic.

MODIFIED WAVE MODEL FORECAST FOR LAKE ERIE <-- DON'T EDIT THIS LINE
MODEL RUN TIME 02/18/92-00Z <-- DON'T EDIT THIS LINE

WATER TEMPERATURE [34]

VALID TIME	WESTERN OR NORTHERN WIND	TA	CENTRAL WIND	TA	EASTERN OR SOUTHERN WIND	TA
18/06Z	[1219]	[36]	[1218]	[36]	[1218]	[33]
18/12Z	[1121]	[37]	[1122]	[36]	[1123]	[34]
18/18Z	[1515]	[43]	[1416]	[43]	[1317]	[41]
19/00Z	[1815]	[43]	[1715]	[42]	[1715]	[39]
19/06Z	[2118]	[41]	[2116]	[42]	[2115]	[42]
19/12Z	[2317]	[39]	[2216]	[40]	[2215]	[41]
19/18Z	[2516]	[42]	[2415]	[44]	[2414]	[44]
20/00Z	[2821]	[38]	[2719]	[40]	[2717]	[40]

SEE NEXT PAGE FOR GENERAL INSTRUCTIONS...OTHERWISE STRIKE ENTER HERE---> [ ]

Figure 2. Modified AFOS Wave Model Forecast Message.

ZCZC CLEADAGLM CE
TTAA00 KCLE DDHHMM

2/12/92 1715Z

TO: ALL GREAT LAKES WSFOS
FROM: WSFO CLE

THE MODIFIED CLEVELAND WAVE MODEL IS NOW RUNNING. THE FOLLOWING IS A ROUNDUP OF THE GUIDANCE BEING USED FOR THIS MODEL RUN:

LAKE	TYPE OF GUIDANCE USED
SUPERIOR	MODIFIED GUIDANCE
MICHIGAN	UN-MODIFIED GUIDANCE
HURON	MODIFIED GUIDANCE
ERIE	UN-MODIFIED GUIDANCE
ONTARIO	MODIFIED GUIDANCE

THE MODEL RUN SHOULD BE COMPLETE WITHIN THE NEXT 45 MINUTES.

NOTE: MODIFIED MEANS THAT A MODIFIED GWN GUIDANCE PRODUCT WAS RECEIVED FOR THAT LAKE IN TIME FOR THIS MODEL RUN.

Figure 3. AFOS wave model guidance message.

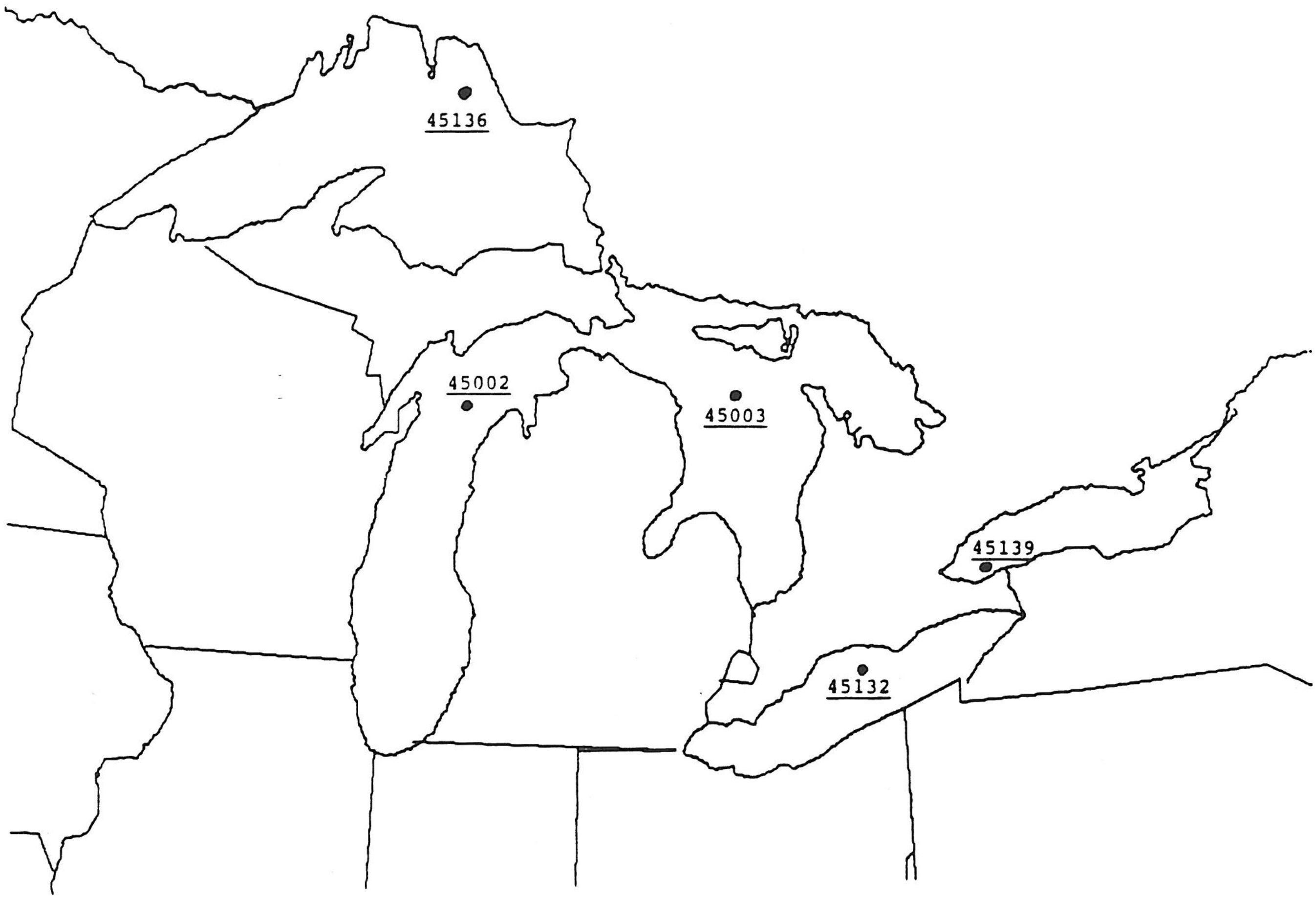

Figure 4. Buoys used in case study.

GREAT LAKES MARINE FORECAST
NATIONAL WEATHER SERVICE CLEVELAND OH
1000 AM EST MON OCT 28 1991

WEATHER SYNOPSIS FOR THE GREAT LAKES

24 HOUR FORECAST POSITIONS BEGINNING AT 1 PM EST MONDAY...HIGH PRESSURE 30.85 INCHES IN EXTREME NORTHERN QUEBEC WITH A RIDGE SOUTH ACROSS THE LOWER LAKES WILL MOVE VERY SLOWLY EAST TO THE ST. LAWRENCE VALLEY. LOW PRESSURE 29.90 INCHES JUST NORTH OF LAKE WINNIPEG WITH A COLD FRONT SOUTH TO A SECOND LOW 29.40 INCHES IN KANSAS WILL MOVE TO HUDSON BAY WITH THE FRONT TO THE SECOND LOW IN MINNESOTA AND ON SOUTH TO ARKANSAS.

ADDITIONAL 12 HOUR OUTLOOK...THE RIDGE OF HIGH PRESSURE WILL MOVE EAST OF THE GULF OF THE ST. LAWRENCE AND THE NEW ENGLAND STATES. THE MINNESOTA LOW WILL MOVE TO CENTRAL ONTARIO NORTH OF LAKE SUPERIOR WITH THE COLD FRONT THROUGH LAKE SUPERIOR TO ARKANSAS.

Figure 5. Weather synopsis for the Great Lakes issued at 1000 AM EST October 28, 1991.

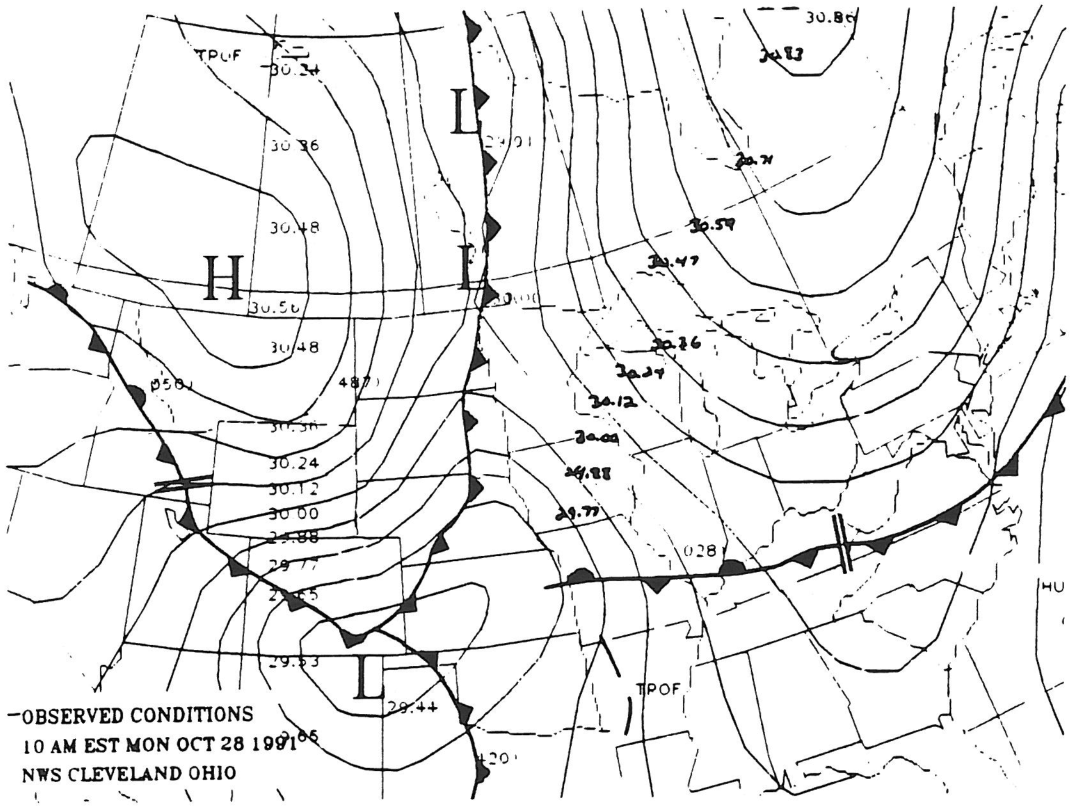

Figure 6. Surface analysis for 1000 AM EST October 28, 1991.

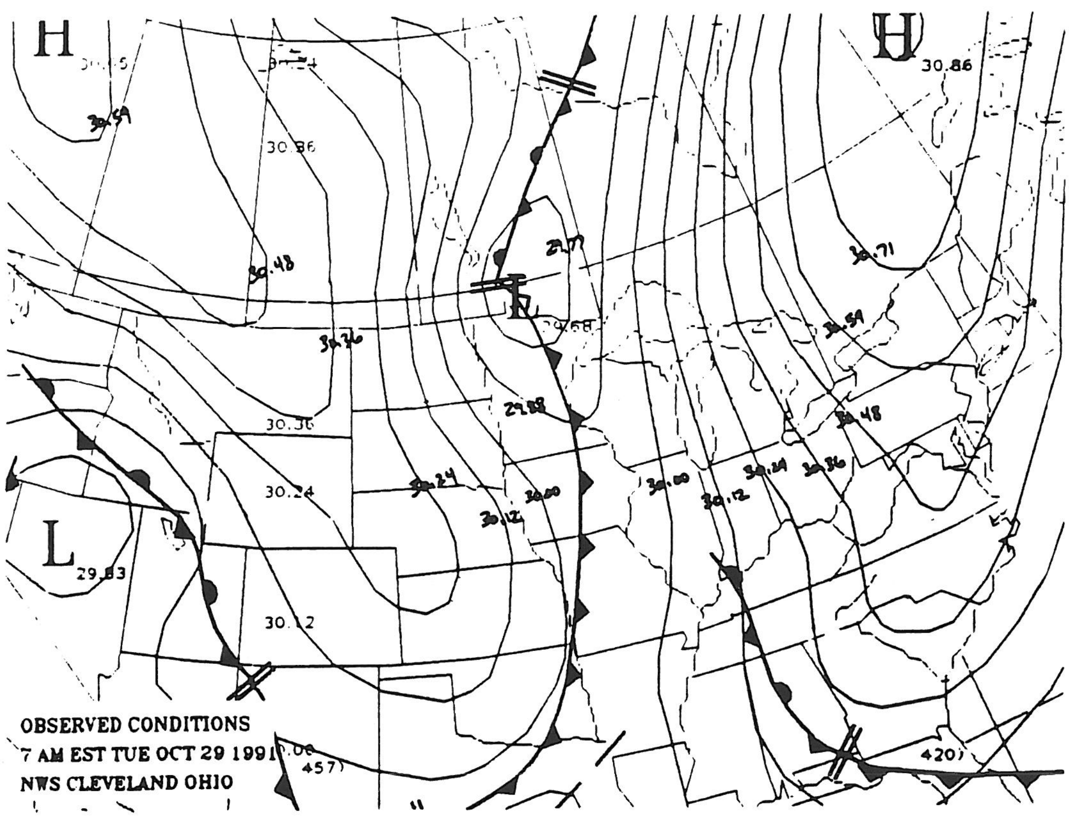

Figure 7. Surface analysis for 700 AM EST October 29, 1991.

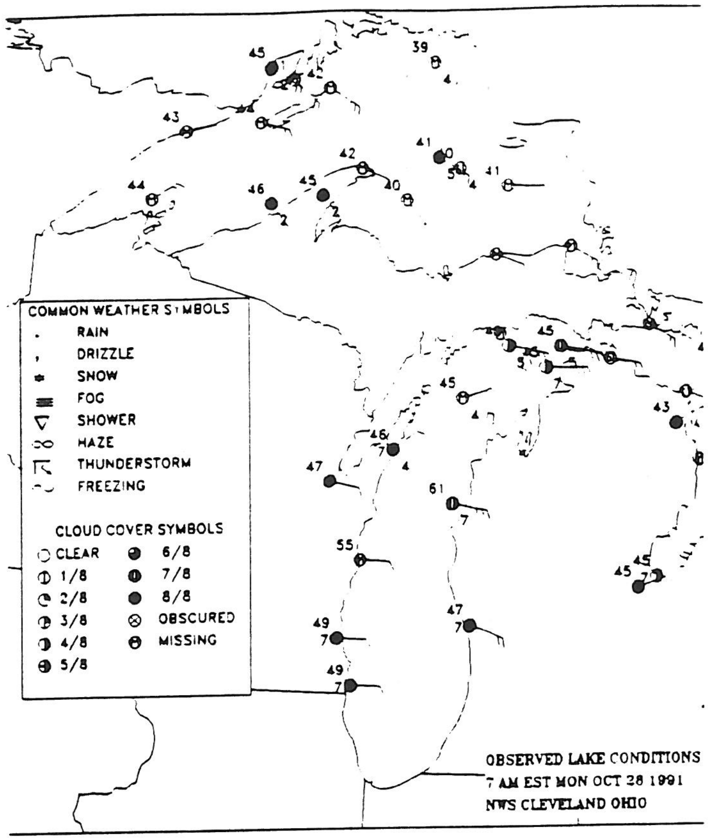

Figure 8. Observed lake conditions (Western Lakes) at 700 AM EST October 28, 1991.

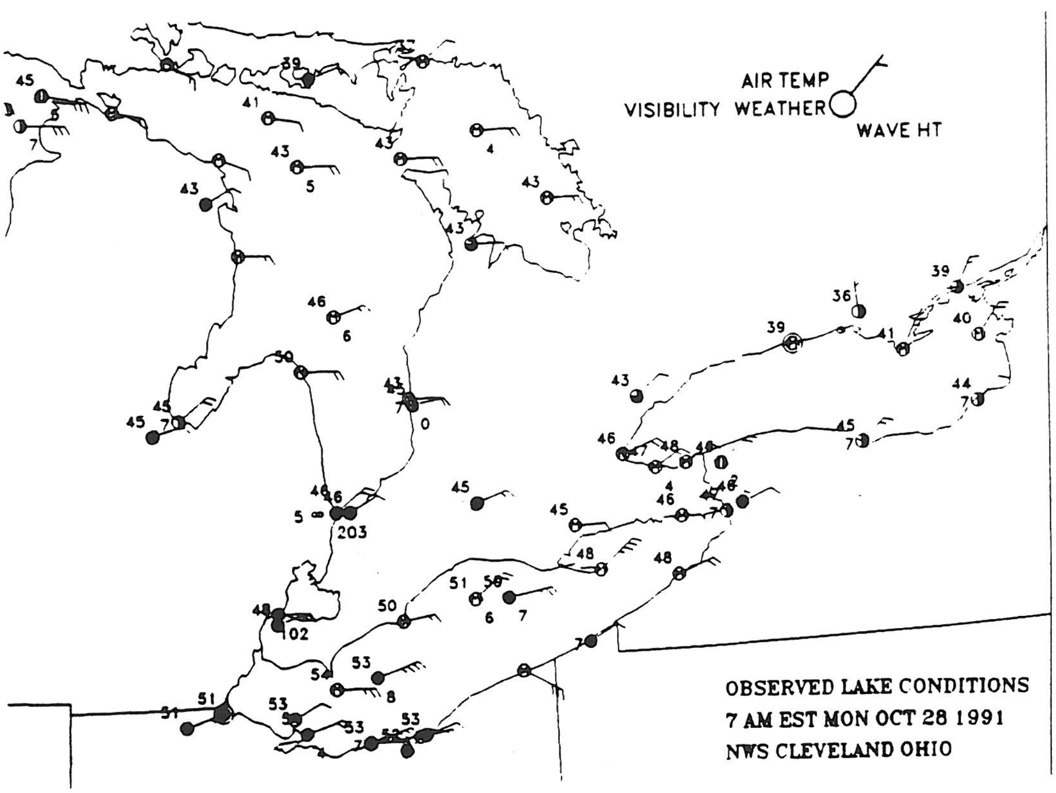

Figure 9. Observed lake conditions (Eastern Lakes) at 700 AM EST October 28, 1991.

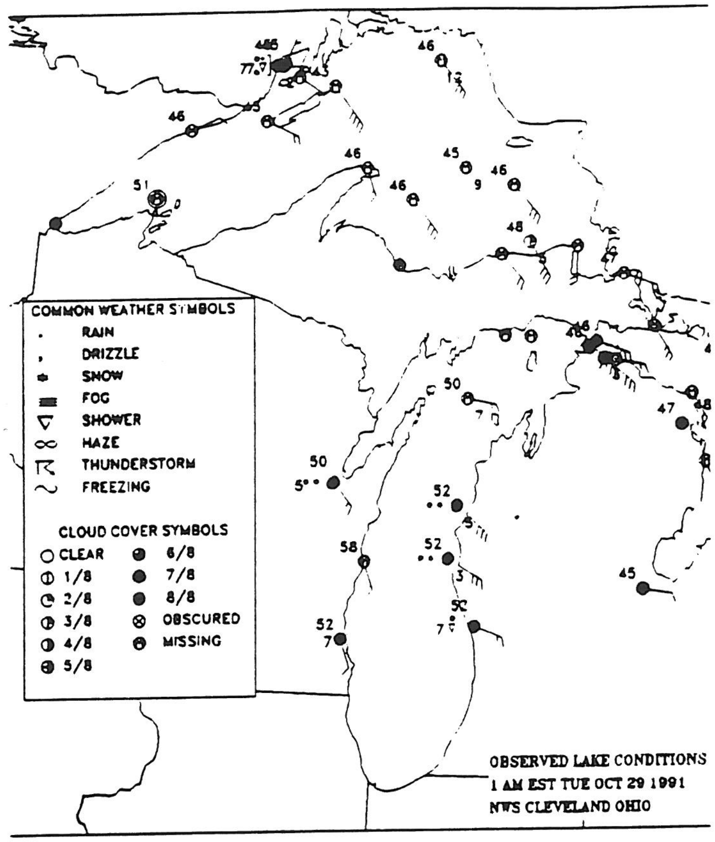

Figure 10. Observed lake conditions (Western Lakes) at 100 AM October 29, 1991.

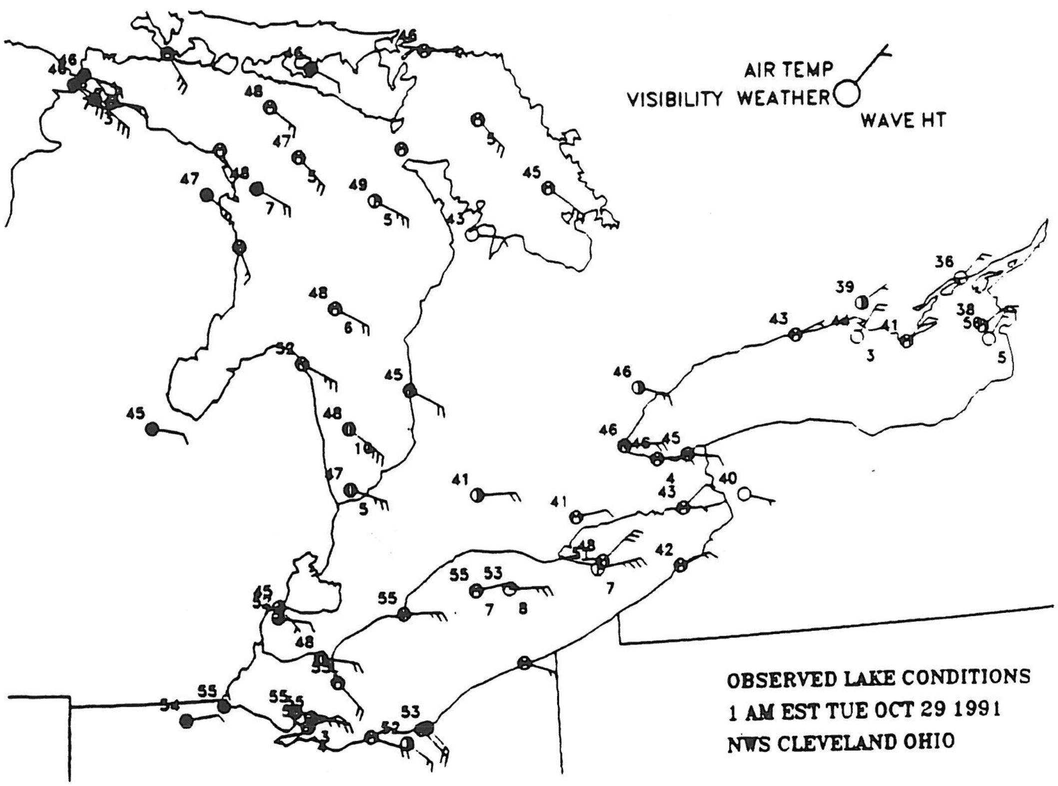

Figure 11. Observed lake conditions (Eastern Lakes) at 100 AM October 29, 1991.

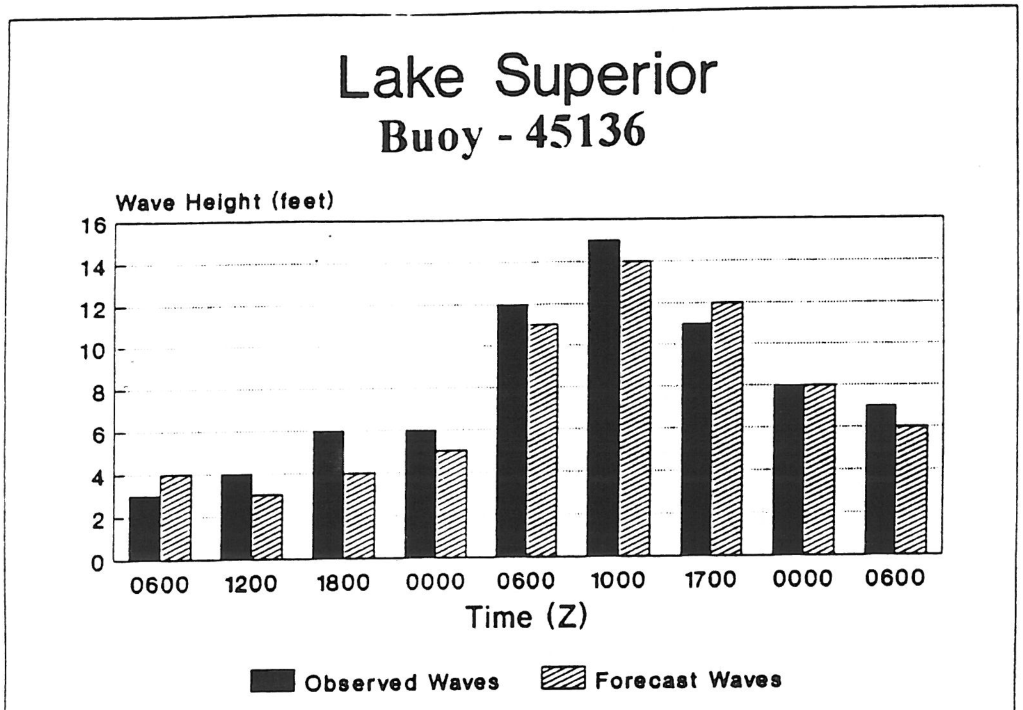

FIGURE 12

Figure 12. Plot of observed waves vs forecast waves for Lake Superior for 0600 UTC October 28, 1991 to 0600 UTC October 30, 1991.

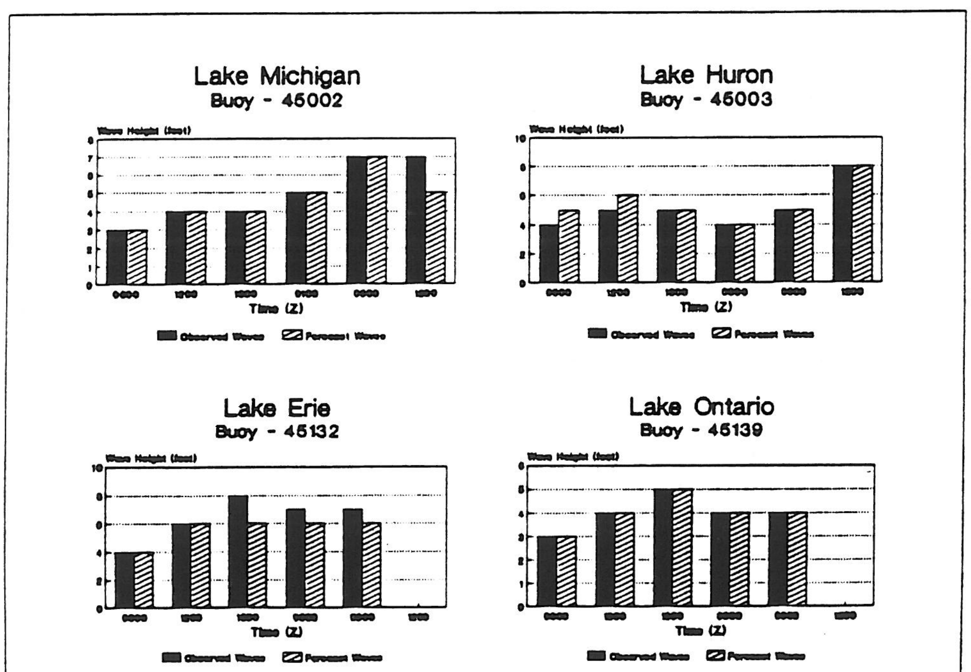

FIGURE 13

Figure 13. Plot of observed waves vs forecast waves for Lakes Michigan, Huron, Erie, and Ontario for 0600 UTC October 28, 1991 to 1200 UTC October 29, 1991.

Lake Superior Buoy 45136 Water Temp $45^{\circ}F$

DATE	TIME	AIR TEMP	WIND	GUST	INPUT WIND	WAVE	FCST WAVE	DIFF
10/28	0600	39	0718	19	0718	3	4	-1
10/28	1200	39	1318	19	1318	4	3	1
10/28	1800	41	1318	21	1318	6	4	2
10/29	0000	45	1219	23	1221	6	5	1
10/29	0600	46	1429	37	1433	12	11	1
10/29	1000	44	1431	37	1435	15	14	1
10/29	1200	Missing...						
10/29	1700	44	1527	33	1530	11	12	-1
10/29	1800	Missing...						
10/30	0000	45	1519	23	1530	8	8	0
10/30	0600	41	2423	29	2425	7	6	1

Lake Michigan Buoy 45002 Water Temp $50^{\circ}F$

DATE	TIME	AIR TEMP	WIND	GUST	INPUT WIND	WAVE	FCST WAVE	DIFF
10/28	0600	47	0818	21	0819	3	3	0
10/28	1200	45	0716	25	0721	4	4	0
10/28	1800	48	1010	21	1016	4	4	0
10/29	0000	Missing...						
10/29	0100	51	0921	29	0923	5	5	0
10/29	0600	50	1014	29	1025	7	7	0
10/29	1200	51	1614	27	1624	7	5	2

Lake Huron Buoy 45003 Water Temp $46^{\circ}F$

DATE	TIME	AIR TEMP	WIND	GUST	INPUT WIND	WAVE	FCST WAVE	DIFF
10/28	0600	44	0819	23	0820	4	5	-1
10/28	1200	43	0921	25	0923	5	6	-1
10/28	1800	45	1119	23	1122	5	5	0
10/29	0000	47	1118	21	1119	4	4	0
10/29	0600	47	1419	21	1420	5	5	0
10/29	1200	46	1421	27	1425	8	8	0

Lake Erie Buoy 45132 Water Temp $55^{\circ}F$

DATE	TIME	AIR TEMP	WIND	GUST	INPUT WIND	WAVE	FCST WAVE	DIFF
10/28	0600	53	0619	23	0621	4	4	0
10/28	1200	51	0523	27	0525	6	6	0
10/28	1800	52	0725	31	0729	8	6	2
10/29	0000	52	0628	29	0628	7	6	1
10/29	0600	55	0626	27	0826	7	6	1
10/29	1200	Missing...						

Lake Ontario Buoy 45139 Water Temp $48^{\circ}F$

DATE	TIME	AIR TEMP	WIND	GUST	INPUT WIND	WAVE	FCST WAVE	DIFF
10/28	0600	50	0514	18	0516	3	3	0
10/28	1200	47	0618	19	0618	4	4	0
10/28	1800	46	0618	21	0620	5	5	0
10/29	0000	47	0914	18	0916	4	4	0
10/29	0600	46	0916	19	0917	4	4	0
10/29	1200	Missing...						

Table 1. Input forecast, model forecast, and observed data for the October 28-30, 1991 case study.